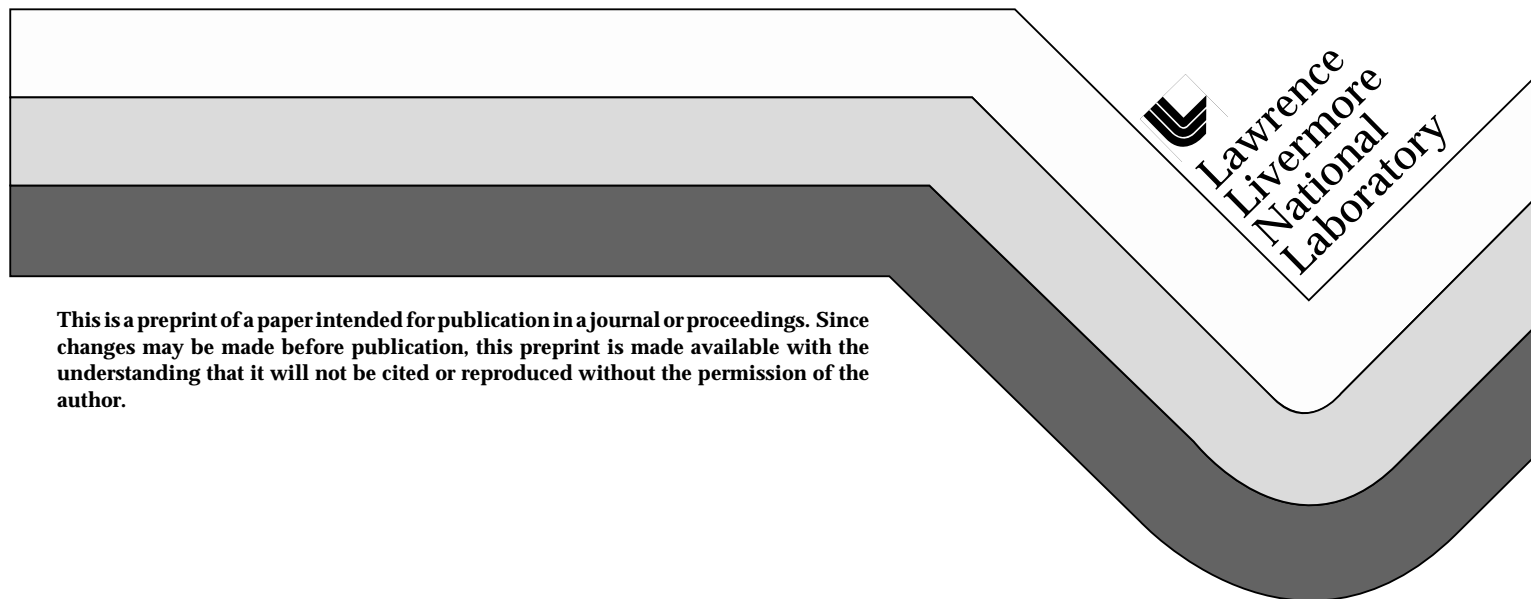


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ABS PLASTIC RPCs

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ABSTRACT

After investigating a number of materials, we discovered that an ABS plastic doped with a conducting polymer performs well as the resistive electrode in a narrow gap RPC. Operating in the streamer mode we find efficiencies of 90-96% with low noise and low strip multiplicities. We have also studied a variety of operating gases and found that a mixture containing SF₆, a non-ozone depleting gas, argon and isobutane gives good streamer mode performance, even with isobutane concentrations of 20% or less.

1. Introduction

Our group at Lawrence Livermore National Laboratory (LLNL) became interested in RPC technology in early 1992 as a triggering system for the GEM muon detector at the SSC. Such a system would operate in a high rate environment (particle fluxes of $\sim 1\text{kHz}/\text{cm}^2$). To construct an RPC that could operate at such incident particle fluxes, we began a search for an electrode material with a low resistivity and a correspondingly fast recharge time. As a result of this search we discovered that a commercially available plastic blend of ABS and a conducting polymer performed well in a narrow gap RPC.

Since the demise of the SSC, we have applied our RPC experience to other experiments. We are developing a multi-layer curved RPC and conducting gas studies for the BaBar experiment at SLAC, pursuing an RPC option for the MINOS experiment at Fermilab/Soudan, and are involved in the RPC effort for the forward-muon detector of the CMS experiment at LHC.

2. Electrode Materials

The plastic RPC, first developed at the University of Rome [1], and its commercially available descendant from General Technica Corporation employ resistive electrodes made from bakelite plastic coated with linseed oil. Bakelite is formulated for its physical, not electrical, properties, and its composition is by no means unique. Bakelites are made by many manufacturers with paper, cloth, glass, fiberglass and other core materials.

In order to avoid the variability associated with the bakelite/linseed oil construction, we decided to look for resistive materials that had a well-defined formulation and that did not need a surface treatment. In addition, we were interested in materials with resistivities lower than the standard bakelite bulk resistivity of $10^{10}\text{-}10^{11}\Omega\text{ cm}$. Since the resistivity affects the recharge time, lower resistivity materials should perform well at higher incident particle rates.

We made resistivity measurements and small RPC chambers (nominally 12 cm x 12 cm) from many candidate materials including a variety of glasses, bakelites and other plastics.

Glasses, except for extremely expensive specialty glass, tended to have high resistivities and were difficult to handle, at least compared to plastics, in small thicknesses (< 1 mm). We were interested in thin electrodes to keep the total resistance low and for keeping the pick-up strips close to the gas gap.

Many of the plastic materials, while they had low resistivity, also had low dielectric strengths. Some materials heated up and melted under high voltage. Two materials made by MiTech Corporation looked promising: M411 and M310. Both materials are manufactured for their electrical properties. They are used in large quantities for static-dispersive packaging for electronics components. M411 is an alloy of PVC and PolytronTM conducting polymer, while M310 is a combination of ABS and Stat-RiteTM conducting polymer.

M411 exhibited lower resistivity than M310 and chambers constructed from both materials attained greater than 90% efficiency. However, we found that after prolonged operation in streamer mode, the M411 material eventually broke down, causing permanent failure. Furthermore, because of the toxic fumes that it emits when burned, PVC poses an ES&H hazard. In contrast, the ABS M310 material has a much higher dielectric strength, did not break down under operation and does not pose an environmental or safety hazard.

The ABS M310 material is easy to handle, can be cut with regular scissors, is extrudable and can be made in a variety of thicknesses. Sheets less than 1 mm thick are flexible enough to be wound on a roll, which makes for easy chamber assembly to arbitrary length and has the potential of industrial production with reel-to-reel techniques. For these reasons ABS M310 became our electrode material of choice.

We have previously reported on these and other materials prior to the demise of the SSC [2], and other groups have experimented with M411 and M310 achieving similar results [3][4].

3. ABS M310 Resistivity

ABS M310 is not an ohmic material. The resistance of the material changes as a function of the applied voltage. For example, the initial bulk resistivity of M310 is about $5 \times 10^9 \Omega \text{ cm}$ for an applied field of 40V/mm. The resistivity increases to $5 \times 10^{11} \Omega \text{ cm}$ for an applied field of 1000V/mm. These resistivity values are valid only for measurements made within the first few minutes of applying the high voltage.

Prolonged high voltage results in an increase in the resistivity. The resistivity is also observed to change with respect to humidity, temperature, and orientation of the applied electric field.

We determined the bulk resistivity of a sample by measuring the current passing through a known area of the material kept at a constant voltage. Initially we made our measurements with the sample exposed to the room environment. We observed large fluctuations in the resistivity that had multi-day time scales. These fluctuations were subsequently eliminated by placing the sample in an enclosure that is slowly flushed with dry nitrogen gas. The system remained in thermal equilibrium with the room and the only temperature control was the room thermostat.

After turning on the high voltage the resistivity steadily climbs until it reaches a plateau value of about $10^{13} \Omega \text{ cm}$ after many hundreds of hours, as shown in Figure 1. The final plateau value depends on the room

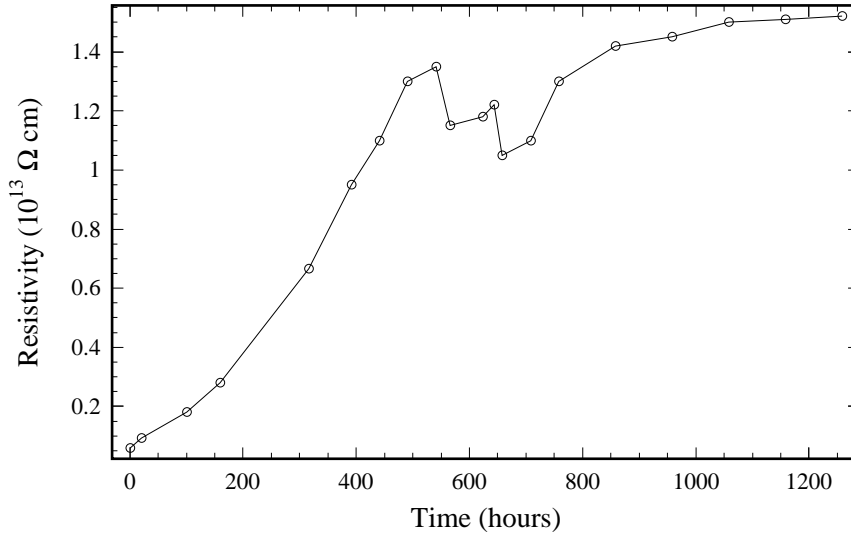


Fig. 1. Bulk resistivity of 0.5 mm thick sample of ABS M310 at 1000 Volts.

temperature and the flow rate of the nitrogen gas. We suspect that the latter effect is due to convection removing the ohmic heat produced by the sample itself. The fluctuations at around 600 hours were due to unintentional changes in the room temperature.

Figure 2 shows the fluctuation of the resistivity from changes in the temperature (set crudely via the wall thermostat). The resistivity can

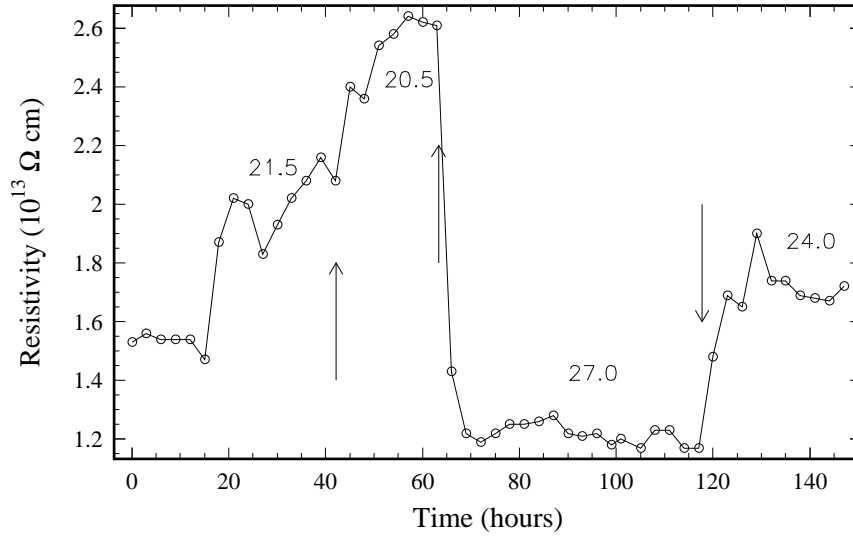


Fig. 2. Effect of temperature change on ABS M310 resistivity. Arrows indicate beginning of temperature change. Numbers indicate equilibrium temperature in Celsius.

change rapidly by a factor of two for a 7 degree difference in temperature. The fluctuations at around 20 hours were again due to unintentional (and unrecorded) temperature changes.

The ABS material also appears to be polarizable. If the polarity of the applied voltage is reversed (in this case from 1000V to -1000V), the resistivity of the sample will decrease for approximately 24 hours and then begin to increase again until it reaches the same plateau as before, as shown in Figure 3. The sample had reached a plateau of $1.6 \times 10^{13} \Omega \text{ cm}$ before the polarity switch. The minimum resistivity after the switch was $2.5 \times 10^{12} \Omega \text{ cm}$ which occurred at about 24 hours after the polarity change.

It is not yet clear how these measurements relate to the conditions the ABS experiences in an operating RPC. Once the ABS charges up, there should be no electric field across the material and little change in its resistance. In a localized region near a streamer discharge, an electric field is produced for a short amount of time while the region charges up again. We estimate that the instantaneous electric field across a region of uncharged ABS in an operating RPC is about 1000V/mm. The data in Figures 1-3 were taken with a higher field, 2000V/mm, in order to exaggerate the effects. We plan to investigate ways of verifying the

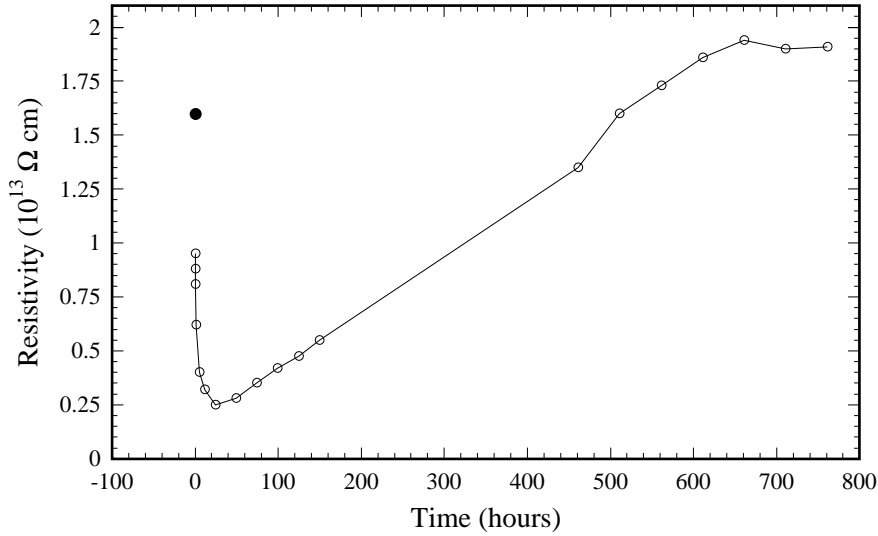


Fig. 3. Effect on ABS M310 resistivity from switching the polarity of the applied high voltage. Data between 150 and 500 hours are missing due to a power failure. The solid circle indicates the resistivity before the polarity switch.

resistivity of the ABS in a functioning RPC.

4. RPC Test Facilities at LLNL

Throughout the RPC R&D program at LLNL, we have developed a number of RPC test facilities. For measuring chamber performance we constructed a large cosmic-ray tower. RPCs are placed on shelves in a $1.5 \text{ m} \times 1.5 \text{ m}$ test rack and are connected directly to LeCroy 4413 discriminators. The discriminator thresholds can be set as low as 15 mV. The discriminators are connected to LeCroy 2229 TDCs which are read-out to a Sun workstation via CAMAC. The total system contains 128 channels. The trigger is provided by the coincidence of a number scintillator paddles (nominally 20 cm by 40 cm).

We are now bringing on-line two additional read-out systems: a Fastbus based system with 480 channels of LeCroy TDCs and ADCs, and a second cosmic-ray tower dedicated to chamber longevity studies. The second system has a separate test stand and electronics similar to the original cosmic-tower.

For precision mixing of RPC gas, we have constructed a four component gas mixing system. The system utilizes mass flow controllers to select the gas mix. The mixture is fed to the RPCs from a buffer bottle that is automatically filled by the mixing system.

5. Chamber Construction

We constructed more than 20 chambers with a 2 mm gas gap (see Figure 4). Chamber size varied from $0.5\text{ m} \times 0.5\text{ m}$, up to $1.2\text{ m} \times 2.4\text{ m}$. We typically used 0.5 mm thicknesses of ABS M310 resistive electrodes. The gap between the electrodes is maintained by 1 cm diameter lucite

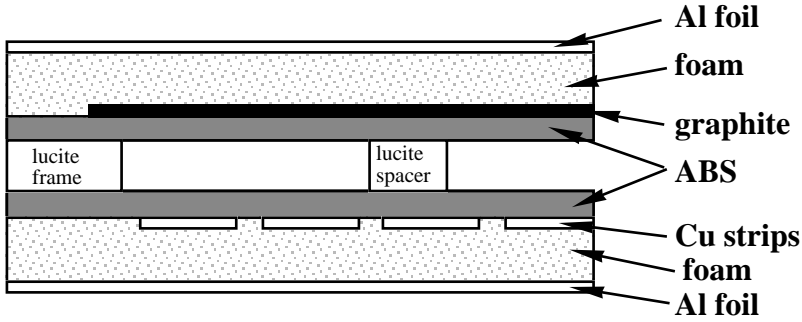


Fig. 4. Standard RPC construction.

buttons. The buttons are arranged with a 10 cm spacing.

One electrode is coated with a graphite paint and connected to a high voltage power supply. Copper read-out strips backed by conducting adhesive are placed on the other electrode. The copper strips provide both the ground plane and read-out. The typical strip pitch is approximately 1.5 cm. The M310 electrodes are glued to foam sheets that provide stiffness and electrical insulation. An aluminum foil backing is attached to the foam, which electrically shields the RPC and forms a transmission line on the side with read-out strips. On the anode side, the copper strips are attached to this foil through terminating resistors at one end of the chamber. The other of the strips is connected to the read-out electronics. The resistors are chosen to match the impedance of the transmission line formed between the strips and the Al ground

plane. The strip impedance is also matched to the impedance of the cables attached to the strips. In most cases, 50 Ω lemo cables were used for the read-out.

6. Chamber Performance

We have focused mainly on the streamer mode of operation. Using standard 15 mV threshold discriminators on 50 Ω cables, without the use of amplifiers, we obtain efficiencies between 90-96% averaged over a region of approximately 30 cm \times 30 cm for a variety of chambers. The noise rate for our chambers is around 1-10kHz/m².

The efficiency plateau and noise rate, measured with cosmic rays, for one of our standard chambers is displayed in Figure 5. The gas used was a freon-less mixture of 78% argon, 20% isobutane 20%, and 2% SF₆. The plateau is wide and the singles rate does not rise rapidly.

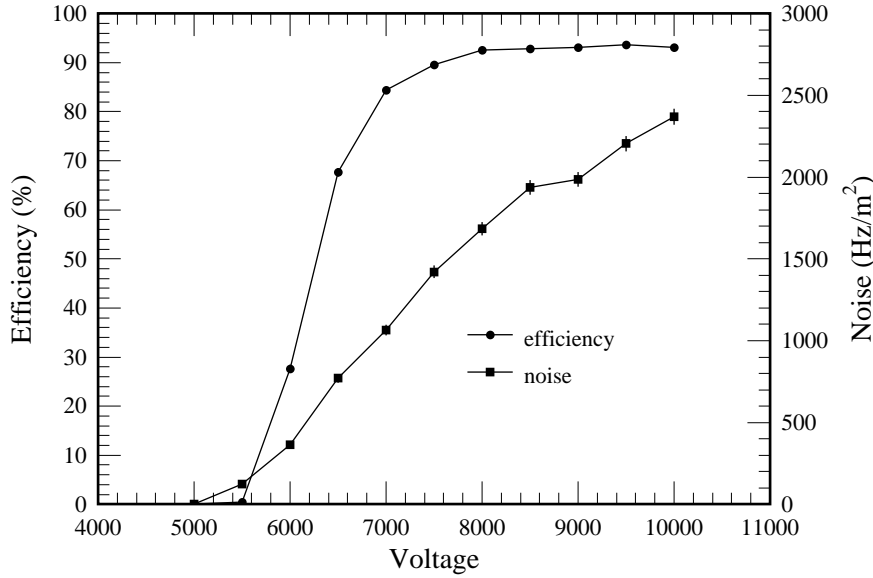


Fig. 5. Efficiency plateau and noise curve for standard ABS RPC.

The details of the chamber's performance at 8 kV are displayed in Figure 6. The timing data, in Figure 6a, is summed over a number of uncalibrated TDC channels and the timing jitter of the trigger has not yet been well characterized, yet the measured timing resolution is better than 3 ns RMS.

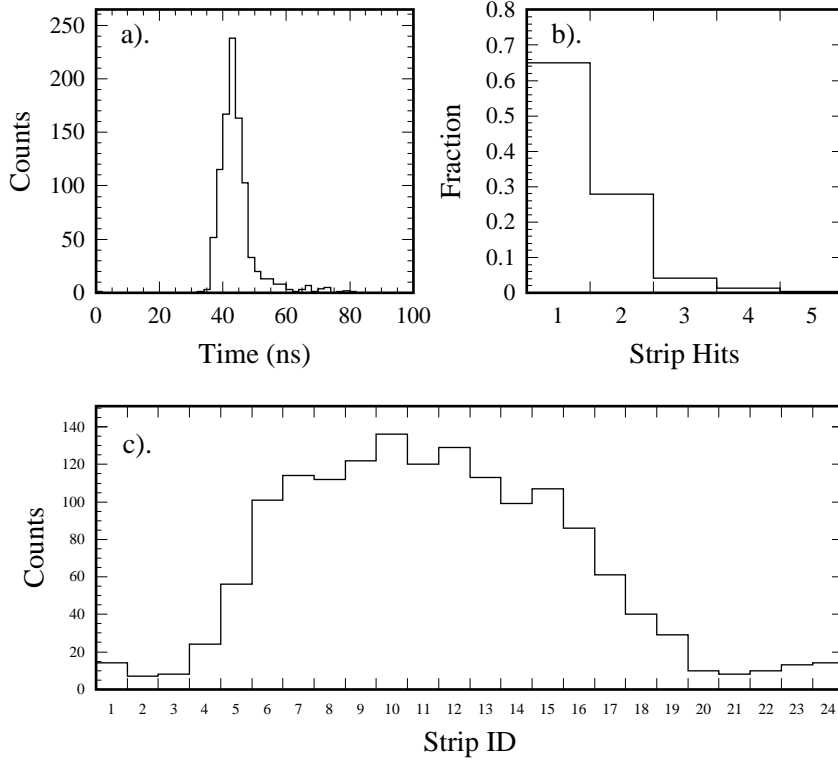


Fig. 6. Standard RPC performance, a) time of first strip hit; b) fraction of events with N strip hits; c) hit population for all read out strips. Data from same RPC as in Figure 5.

Figure 6b shows the hit multiplicity, sometimes called cluster size. Even at our low discriminator threshold of 15 mV, we observe low multiplicities. The average number of strips firing in an event is 1.6, where 92% of triggers had only one or two strips. We have no external tracking to exclude particle trajectories that pass between two strips.

Figure 6c shows the hit distribution for every strip that was read-out, summed over all triggers. The trigger covers a fairly wide region of the chamber, about 18 strips (at a strip pitch of 1.6 cm).

We have been running various chambers for up to 10 months continuously. Throughout that time, however, we varied the gas (different components and different concentrations) and the high voltage. We noted that from two chambers that are of similar construction and were

operated nearly simultaneously, one showed a change in performance after many months of running and the other did not. We do not yet know if this was due to an intrinsic property of the RPC or represents damage induced by external sources.

Long term performance is essential and we have begun to make long term tests. Already, we have discovered that Epon 815, an epoxy adhesive that we had been using to join the M310 to an insulating backing, degrades the graphite coating on the high voltage plane.

7. Cylindrical RPC

Because the M310 material is thin and flexible, we developed a concept for a multi-gap, curved RPC for the BaBar [5] experiment. By placing an RPC between the electromagnetic calorimeter and the superconducting solenoid cryostat, the charged particle detection efficiency improves. This improves the detection capability for neutral kaons and hadronic punch-through from the calorimeter.

We constructed a 1 m prototype with the appropriate inner radius of 1.4 m. The prototype achieved an efficiency of 90%, but had excess noise concentrated in a few strips. We disassembled the prototype to study this effect.

8. Gas Studies

The standard RPC operating gas for streamer mode contains a large fraction of flammable isobutane ($\sim 40\%$) and Freon 13B1 which is an ozone-depleting compound. Reducing the flammability and eliminating the freon are important goals for producing a gas that meets current ES&H requirements. All of the studies mentioned below use a 2mm gap RPC operated in streamer mode with 15 mV discriminators and no amplifiers.

We have conducted a number of tests with isobutane concentrations as low as 5%. We find that we can operate our chambers with good efficiency plateaus at concentrations of about 20% with 2% F13B1. The timing distribution is significantly worse than with standard gas (by a factor of two).

For F13B1 substitutes we investigated Freon 116, Freon 23, Freon 14, and SF_6 . SF_6 is often used in Van de Graaff and high power transformers to reduce the spark probability. Of these, only mixtures with

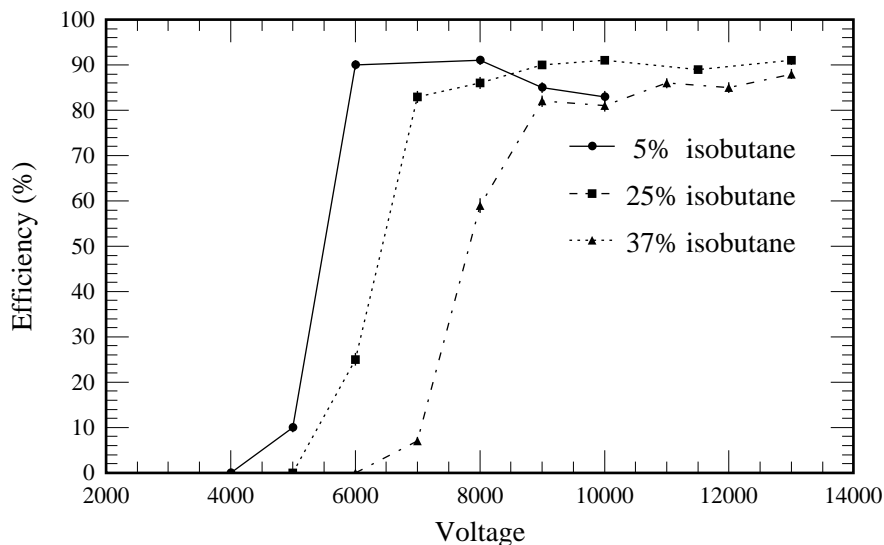


Fig. 7. Efficiency plateaus for gas mixtures with 2% F13B1, various isobutane concentrations and the balance argon.

SF_6 resulted in full efficiency, although F116 and F14 showed some positive effect. Figure 8 shows the performance of various gas mixtures with 20% isobutane, various F13B1 replacements and the balance argon. The mixture with 2% SF_6 is half as flammable as the “standard” streamer gas mix (which contains 37% isobutane) and is ozone-safe.

9. Work In Progress

Our program in RPC R&D is progressing in a number of ways. We are now testing bakelite chambers from General Technica for direct comparison with our ABS chambers. We are studying alternative gases (for flammability and ES&H compliance) that can be used for BaBar. We are building ABS chambers with double-sided graphite to investigate potential performance and construction trade-offs. We are making long-term tests of both bakelite and M310 chambers to study the intrinsic stability and potential harm from gas breakdown. Using our new multi-channel Fastbus ADC system, we are looking at the charge response of RPCs. We are preparing for a test of the shower response of our RPCs

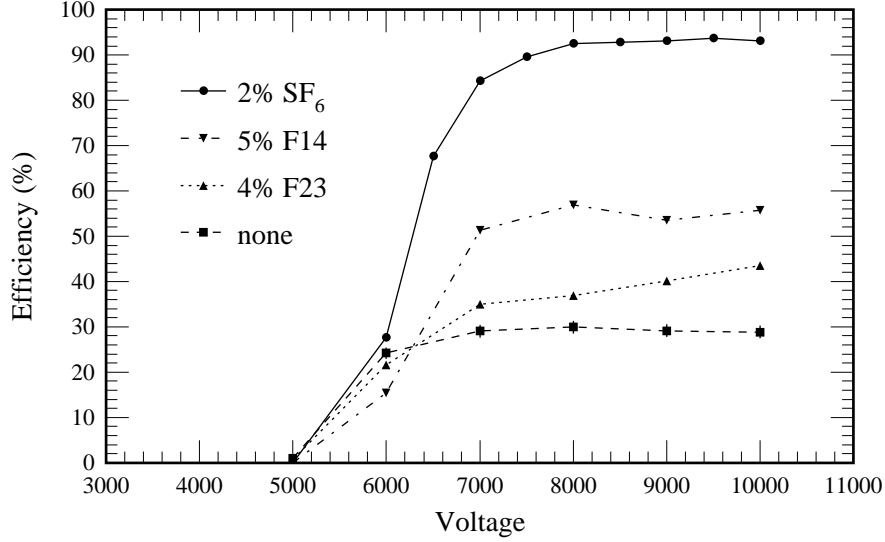


Fig. 8. Efficiency plateaus for gas mixtures with 20% isobutane, various F13B1 replacements and the balance argon.

using the electron beam at the SLAC Final Focus Test beam.

10. Summary

We have demonstrated that RPCs constructed from ABS M310 have nearly the same performance as the standard bakelite chambers. The ABS material has a number of advantages: the resistivity of the material is controlled by the manufacturer, it is inexpensive, does not require a surface treatment, and is easy to handle.

We have also demonstrated a successful gas mixture consisting of argon, isobutane and SF₆ that is free from ozone-depleting compounds and has reduced flammability compared to the standard streamer mode RPC gas. We are now investigating the long-term stability of ABS RPCs operated in this manner, as well as pursuing a number of new operating modes.

11. Acknowledgments

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